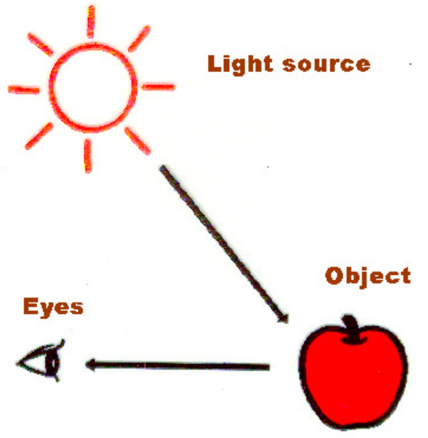
CMPG-767 Digital Image Processing

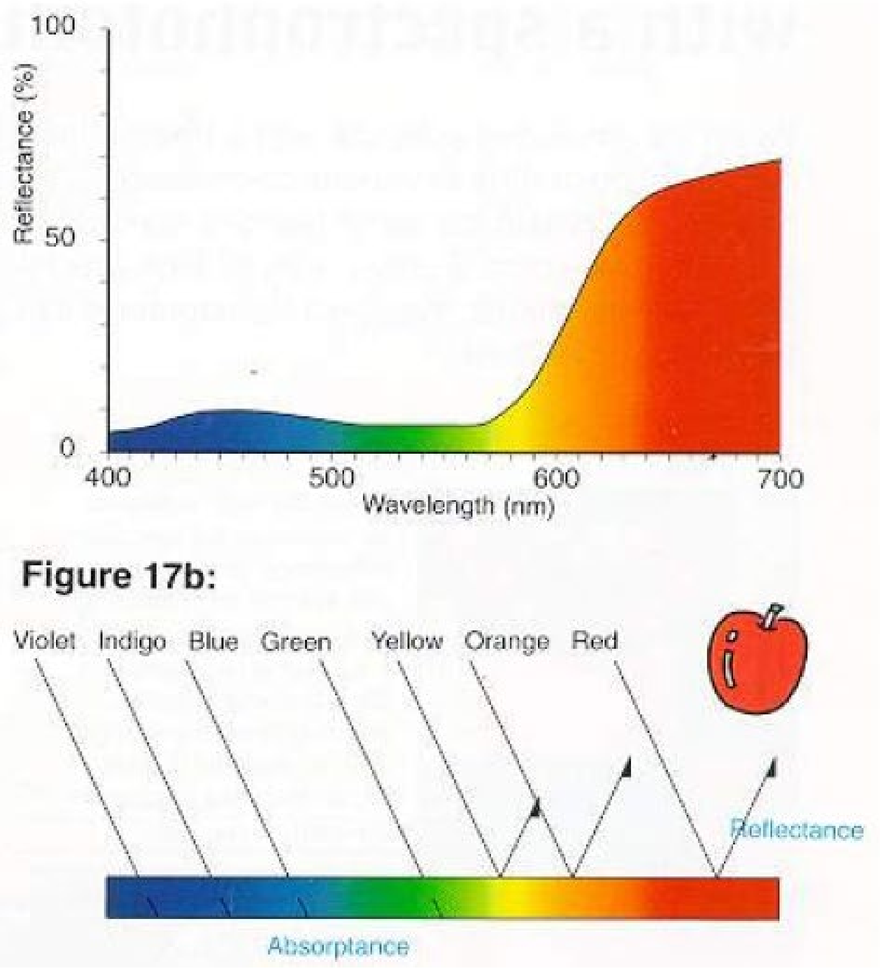
PROCESSING OF COLOR IMAGES

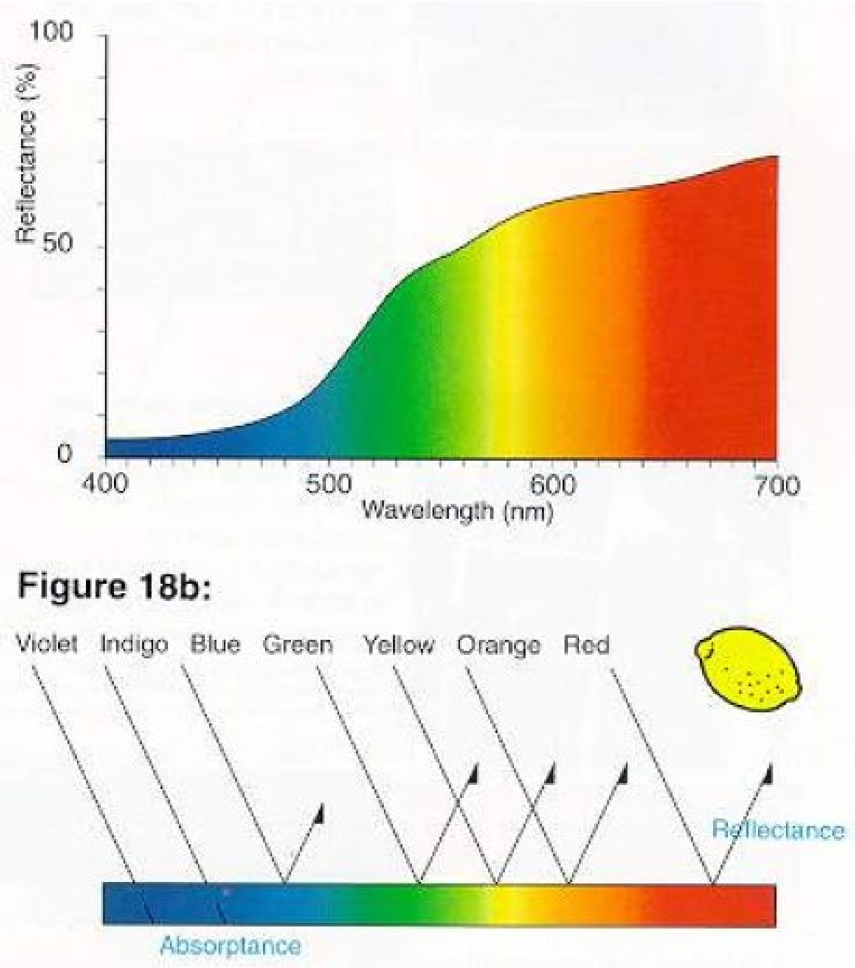
Color Fundamentals

- Color can only exist when three components are present: a viewer, an object, and light
- When white light hits an object, it selectively blocks some colors and reflects others
- Only the reflected colors contribute to the viewer's perception of color



Color Fundamentals





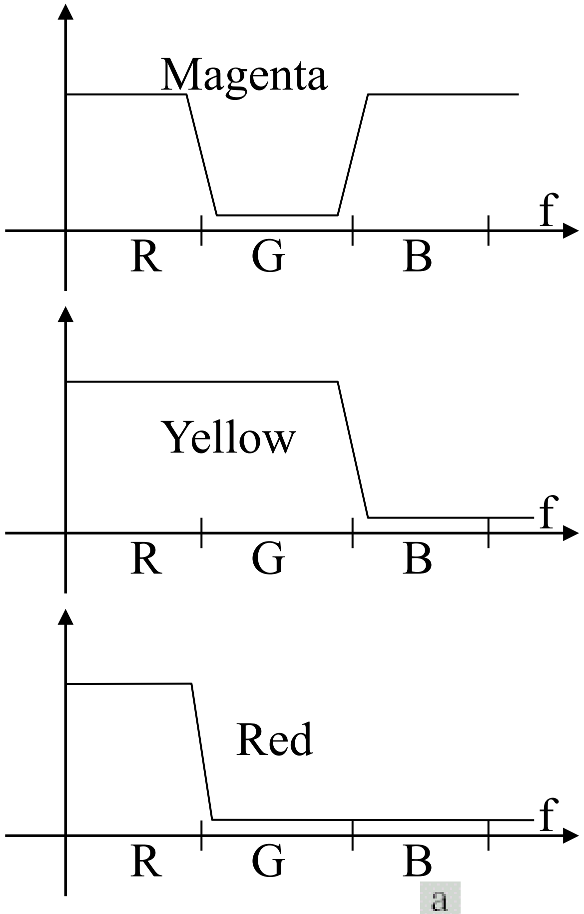
Color Fundamentals

- Primary colors of light : Red, Green, Blue
    - ➢ The specific wavelength values to the three primary colors
        - ➢ Blue= 435.8 nm, green= 546.1 nm, red= 700 nm
- Secondary colors of light : **Cyan**, Magenta, **Yellow**
- The primary colors should be added to produce secondary colors of Light
    - Magenta (Red+Blue)
    - Cyan (Green+ Blue)
    - Yellow (Red+ Green)

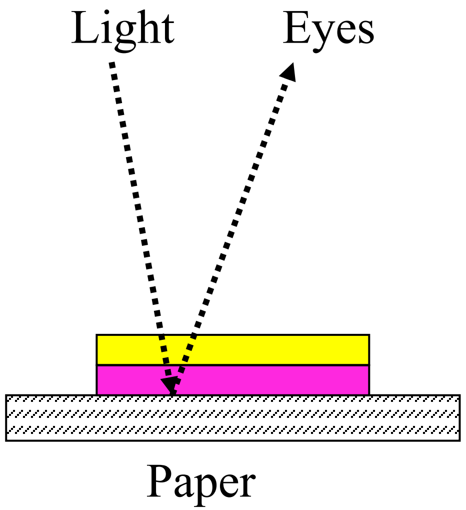
Color Fundamentals

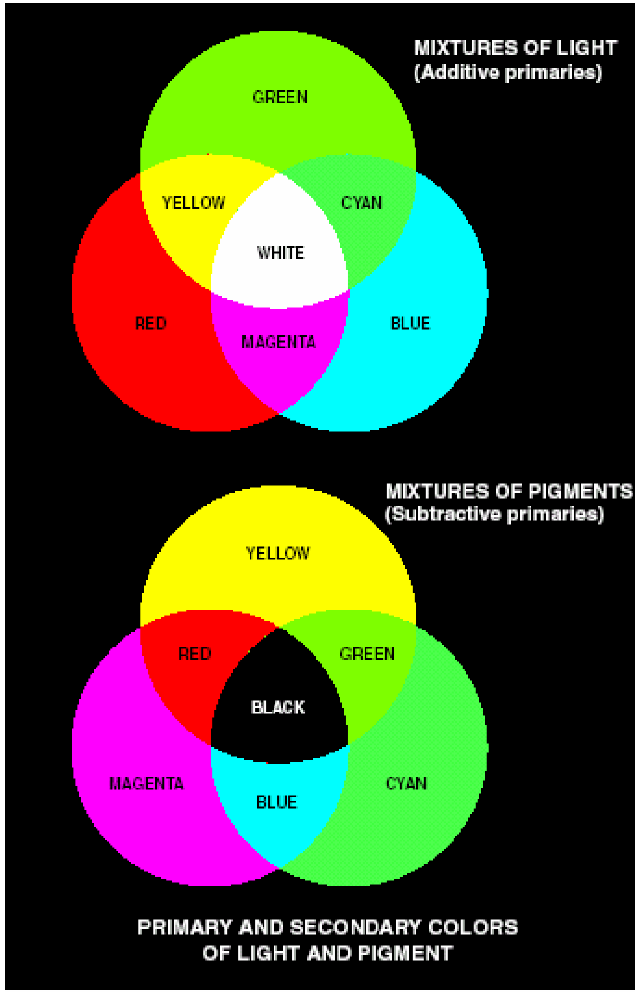
- Primary colors of pigments or colorants
  - cyan, magenta, yellow
  - A primary color of pigments is defined as one that subtracts or absorbs *a primary color of light and reflects or transmits the other two*
- Secondary colors of pigments or colorants
  - red, green, blue
  - Combination of the three pigment primaries, or a secondary with its opposite primary, produces black

Color Fundamentals



$f(x)= i(x)\ \ r(x)$





a
b

FIGURE 6.4 Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lamp Business Division.)

Color Fundamentals

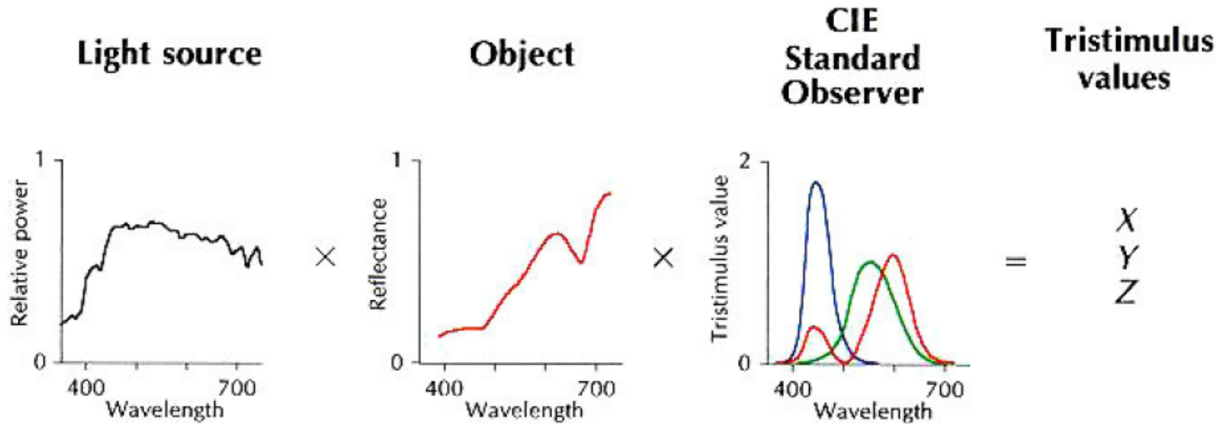
- Characteristics of colors
  - Brightness
    - The chromatic notion of intensity
  - Hue
    - An attribute associated with the dominant wavelength in a mixture of light waves
    - Representing dominant color as perceived by an observer
  - Saturation
    - Referring to relative purity or the amount of white mixed with a hue
    - Saturation is inversely proportional to the amount of white light

Color Fundamentals

- Hue and saturation taken together are called **chromaticity**
  - A color may be characterized by its brightness and chromaticity
  - The amounts of red, green, and blue needed to form any particular color are called the tristimulus values
    - Denoted X(red), Y(green), and Z(blue)

$$x = \frac{X}{X+Y+Z}, \quad y = \frac{Y}{X+Y+Z}, \quad z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1 \ , \ X = \frac{x}{y}Y, Z = \frac{z}{y}Y$$



Human Perception

- Detailed experimental evidences has established that the 6 to 7 million cones in the human eye can be divided into three principal sensing categories, corresponding roughly to red, green and blue

- Approximately

  65% of all cones are sensitive to Red Light,

  33% are sensitive to Green Light

  2% are sensitive to Blue Light

Absorption of Light by red, green and blue cones in Human Eye

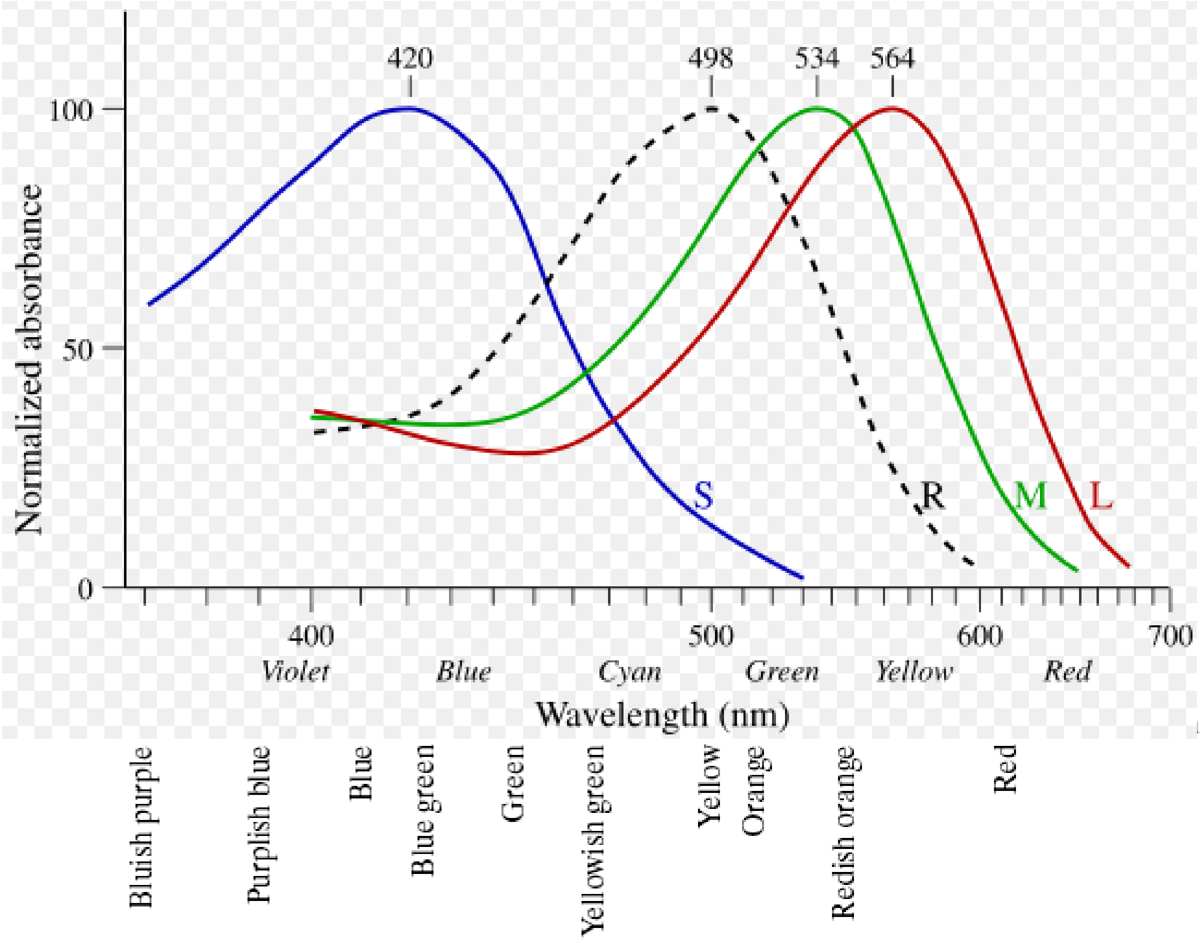


FIGURE 6.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

- Mixing the three primaries or a secondary with its opposite primary colors in the right intensities produces white light

Color Models

- The purpose of a color model (also called Color Space or Color System) is to facilitate the specification of colors in some standard way

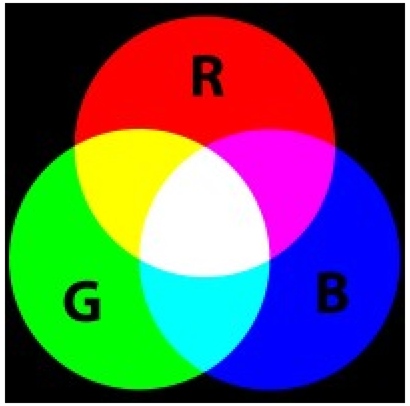
- A color model is a **specification of a coordinate system and a subspace within that system where each color is represented by a single point**

- **Color Models**

RGB (Red, Green, Blue)
CMY (Cyan, Magenta, Yellow)
HSI (Hue, Saturation, Intensity)
YIQ (Luminance,In phase, Quadrature)
YUV (Y' stands for the luma component (the brightness) and U and V are the chrominance (color) components)

RGB color model

- RGB (Red Green Blue) uses additive color mixing, because it describes what kind of light needs to be emitted to produce a given color.
- Additive color mixing: Three overlapping light bulbs in a vacuum, adding together to create white



RGB color model

- In the RGB space, its components measure the intensity and chrominance of light
- The actual information stored in the digital image data is the intensity information in each channel
- If a digital color image is represented using
  8 bit/component precision, then the 24-bit RGB model may represent
  $256 \times 256 \times 256 \approx 16.7$ million colors

RGB color model

- Each color is represented in its primary color components Red, Green and Blue
- This model is based on Cartesian Coordinate System
- This is the model used for active displays such as television and computer screens

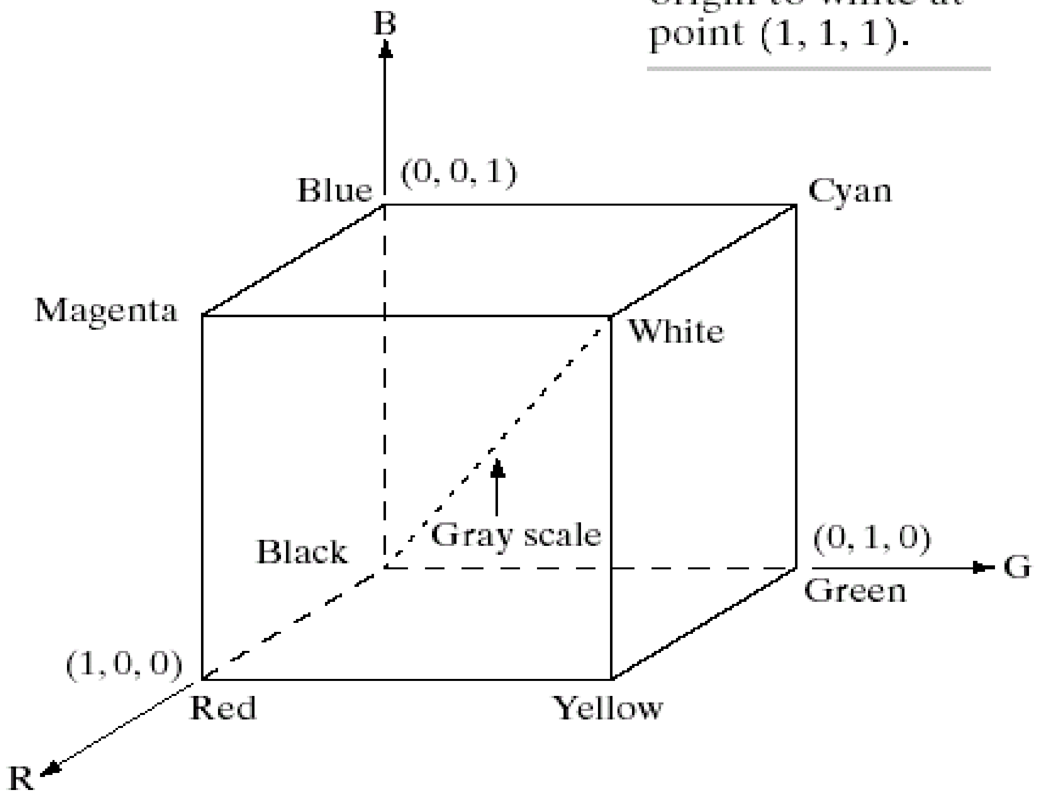


FIGURE 6.7 Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).

RGB color model

- The RGB model is usually represented by a unit cube with one corner located at the origin of a three-dimensional color coordinate system,
  the axes being labeled R, G, B, and having a range of values [0, 1].
- The origin (0, 0, 0) is considered **black** and the diagonally opposite corner (1, 1, 1) is called white. The line joining black to white represents a gray scale and has equal components of R, G, B.

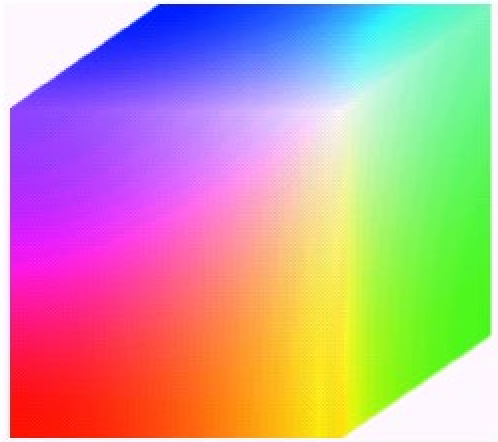


FIGURE 6.8 RGB 24-bit color cube.

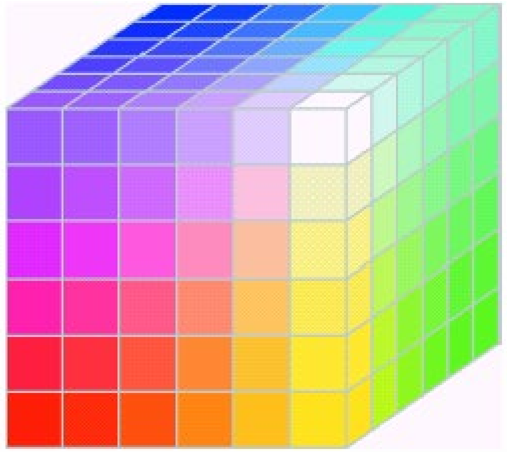


FIGURE 6.11 The RGB safe-color cube.

It is important to note that not all possible 8-bit gray colors are included in the **216 safe** colors

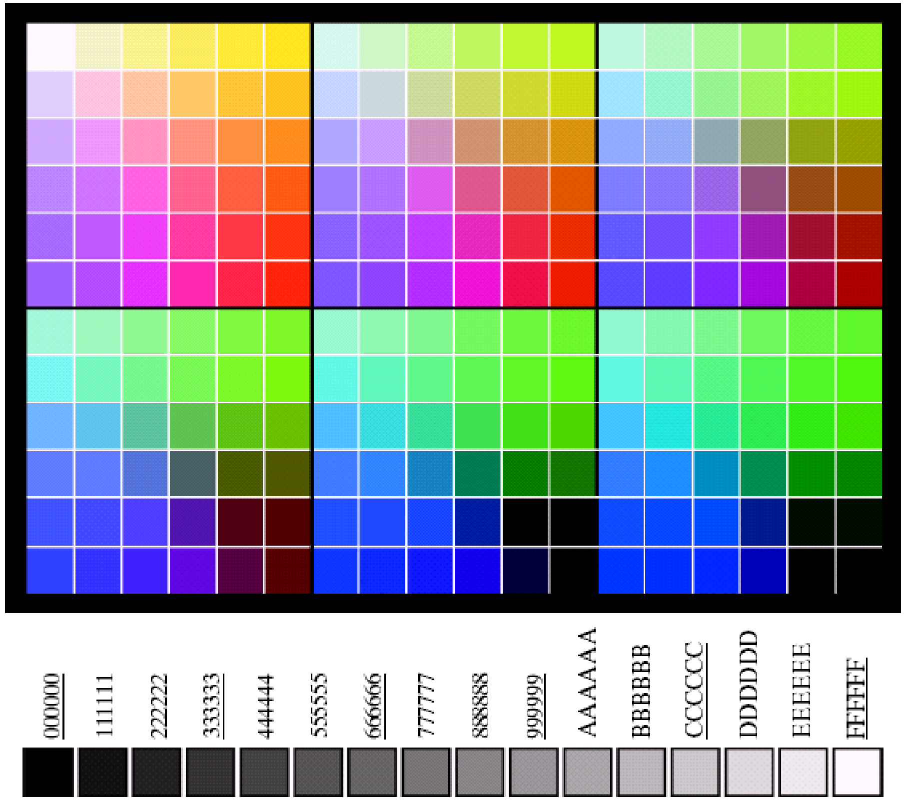
RGB color model

- The set of ***safe*** *RGB colors*
  - A subset of colors that are likely to be reproduced faithfully, reasonably independently of viewer hardware capabilities
  - They are also called the set of all-system-safe colors, safe Web colors, safe browser colors
  - 216 safe colors in RGB color model
    - On the assumption that 256 colors is the minimum number of colors that can be reproduced faithfully by any system, forty of these 256 colors are known to be processed differently by various operating systems, leaving only 216 colors that are common to most systems

Generating RGB image

Number System	Color Equivalents					
Hex	00	33	66	99	CC	FF
Decimal	0	51	102	153	204	255

TABLE 6.1 Valid values of each RGB component in a safe color.



a
b

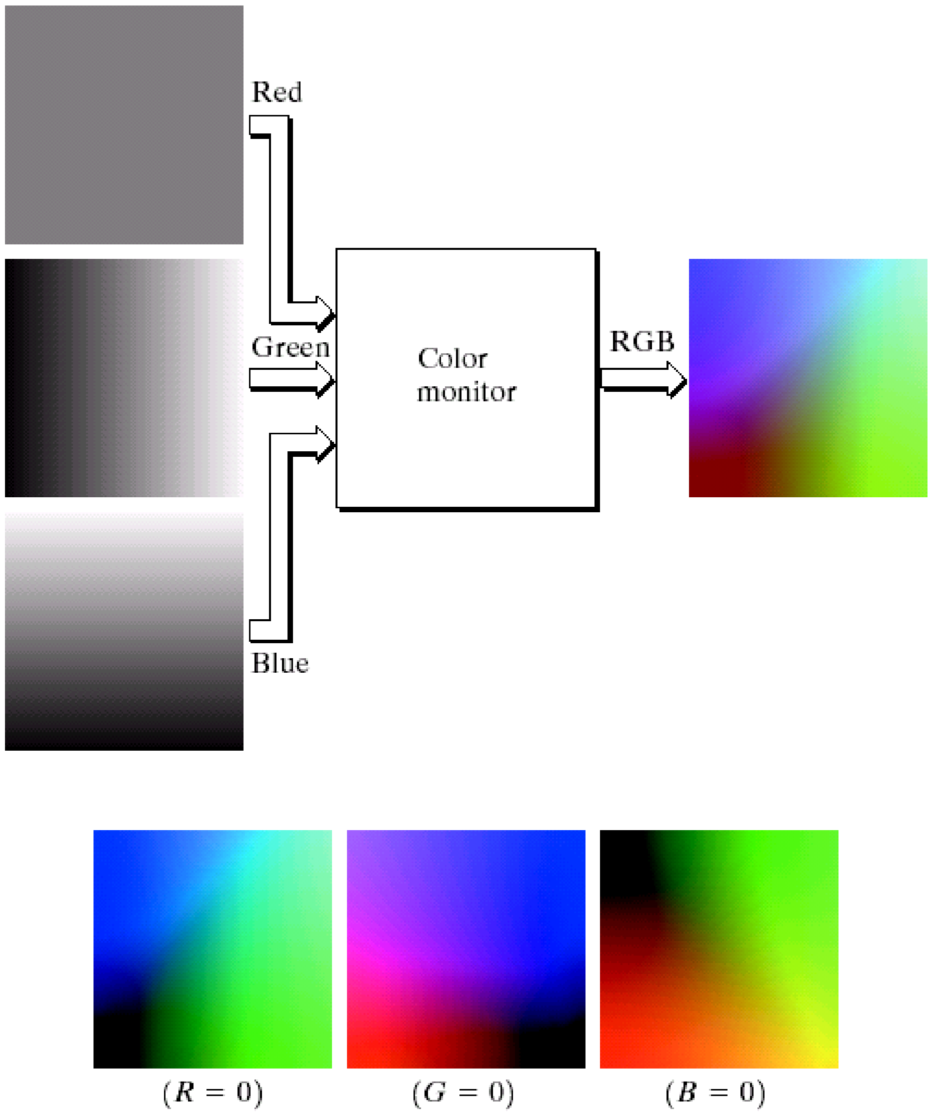
FIGURE 6.10 (a) The 216 safe RGB colors. (b) All the grays in the 256-color RGB system (grays that are part of the safe color group are shown underlined).

RGB color model

- Generating the RGB image

a
b

FIGURE 6.9
(a) Generating
the RGB imag
the cross-sectic
color plane
(127, G, B).
(b) The three
hidden surface
planes in the cc
cube of Fig. 6.8.



RGB Space and YUV Space

- RGB pixel intensities can be transformed to the YUV space as follows

$$\begin{pmatrix} Y \\ U \\ V \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.14713 & -0.28886 & 0.436 \\ 0.615 & -0.51499 & -0.10001 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

- Where Y is a luminosity (luma) information (channel), U and V are chromatic (differences U=B-R-G, V=R-G-B) channels

RGB Space and YUV Space

- RGB pixel intensities can be restored from the YUV space as follows

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 1 & 0 & 1.13983 \\ 1 & -0.39465 & -0.5806 \\ 1 & 2.03211 & 0 \end{pmatrix} \begin{pmatrix} Y \\ U \\ V \end{pmatrix}$$

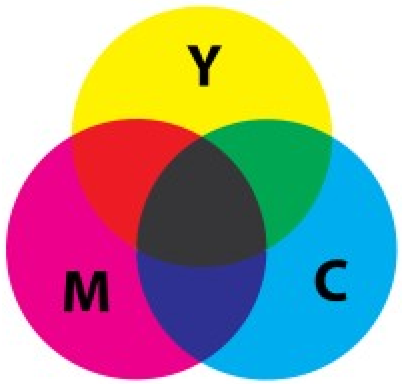
- Where Y is a luminosity information (channel), U and V are chromatic (differences U=B-R-G, V=R-G-B) channels

YUV space and JPEG compression

- YUV space is used in JPEG image compression
- To apply JPEG compression, an RGB image shall be transformed into an YUV image
- Then, JPEG compression is applied to the YUV channels. This makes it possible to reach a higher compression rate, because the U and V channels can easily be compressed with a significantly higher rate (up to 90% without losing any significant information) rather than any of RGB channels

CMYK color model

- CMYK (Cyan Magenta Yellow Key) uses subtractive color mixing used in the printing process, because it describes what kind of inks need to be applied so the light reflected from the substrate and through the inks produces a given color.
- Subtractive color mixing: Three splotches of paint on white paper, subtracting together to turn the paper black



CMY and CMYK Color Model

- Cyan, magenta, and yellow are the secondary colors with respect to the primary colors of red, green, and blue.
- In this model, colors are formed by subtraction, where adding different pigments causes various colors not to be reflected and thus not to be seen. Here, white is the absence of colors, and black is the sum of all of them. This is generally the model used for printing.
- Most devices that deposit color pigments on paper (such as Color Printers and Copiers) requires CMY data input or perform RGB to CMY conversion internally

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

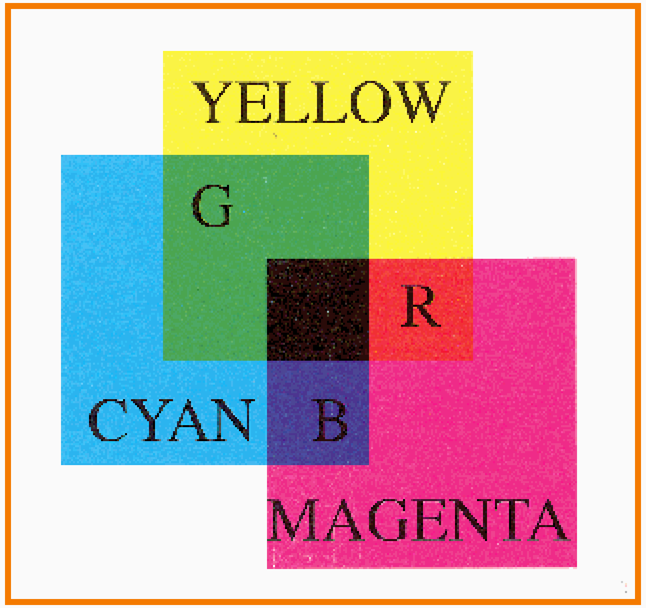
CMY and CMYK Color Model

- CMY is a Subtractive Color Model

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

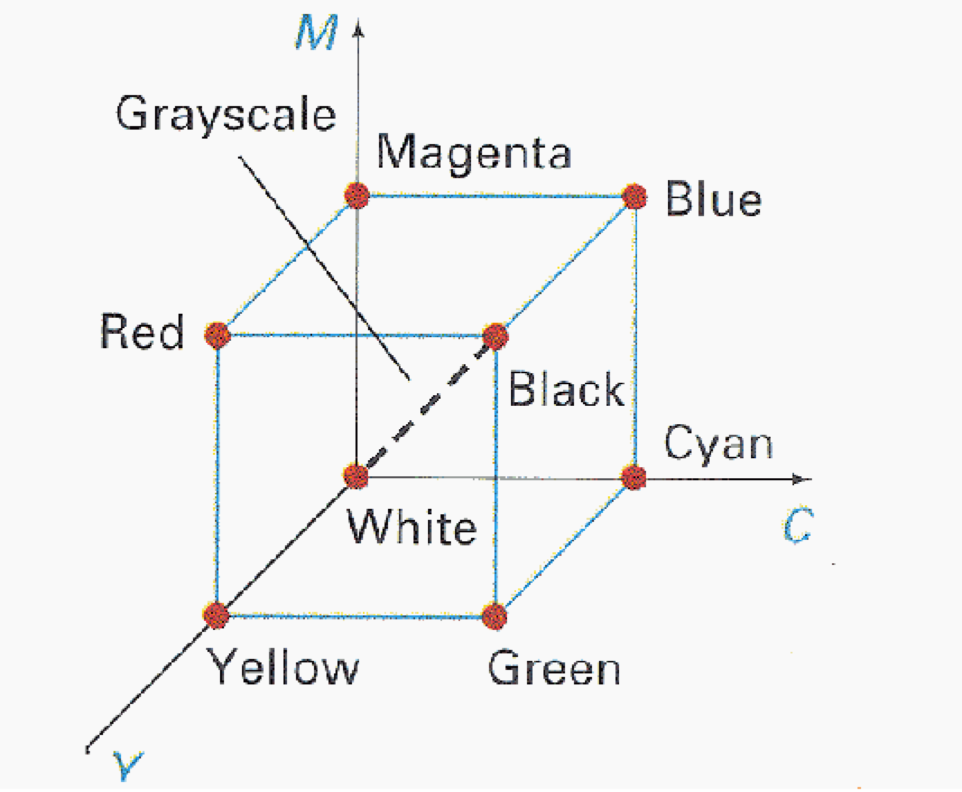
- Equal amounts of Pigment primaries (Cyan, Magenta and Yellow) should produce Black
- In practice combining these colors for printing produces a "Muddy-Black" color
- So in order to produce "True-Black" a fourth color "Black" is added giving rise to CMYK model

CMYK color model



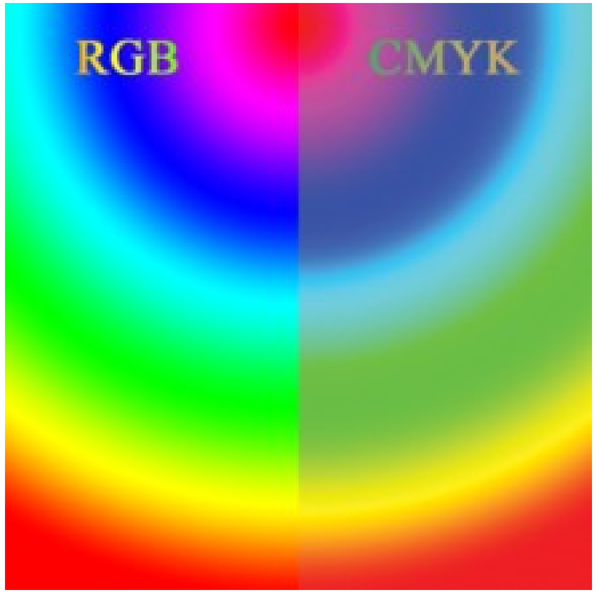
Colors are subtractive

C	M	Y	Color
0.0	0.0	0.0	White
1.0	0.0	0.0	Cyan
0.0	1.0	0.0	Magenta
0.0	0.0	1.0	Yellow
1.0	1.0	0.0	Blue
1.0	0.0	1.0	Green
0.0	1.0	1.0	Red
1.0	1.0	1.0	Black
0.5	0.0	0.0	
1.0	0.5	0.5	
1.0	0.5	0.0	



RGB vs. CMYK

- A comparison of RGB and CMYK color models. This image demonstrates the difference between how colors will look on a computer monitor (RGB) compared to how they will reproduce in a CMYK print process



RGB vs. CMYK

- CMYK color space is used primarily for color printing (the K component characterizes specific properties of a particular printer)

- RGB color space is used for storing color images, their processing (filtering, enhancement), and displaying

HSI Color Model

- Hue (dominant colour seen)
  - Wavelength of the pure colour observed in the signal.
  - Distinguishes red, yellow, green, etc.
  - More the 400 hues can be seen by the human eye.

- Saturation (degree of dilution)
  - Inverse of the quantity of "white" present in the signal. A pure colour has 100% saturation, the white and grey have 0% saturation.
  - Distinguishes red from pink, marine blue from royal blue, etc.
  - About 20 saturation levels are visible per hue.

- Intensity
  - Distinguishes the gray levels.

HSI Color Model

- Usefulness
    - The intensity is decoupled from the color information
    - The hue and saturation are intimately related to the way in which human beings perceive color
    - An ideal tool for developing image procession algorithms based on some of the color sensing properties of the human visual system

HSI Color Model

- Hue and saturation in the HSI color model
  - Hue - Angle from the red axis
  - Saturation - Length of the vector

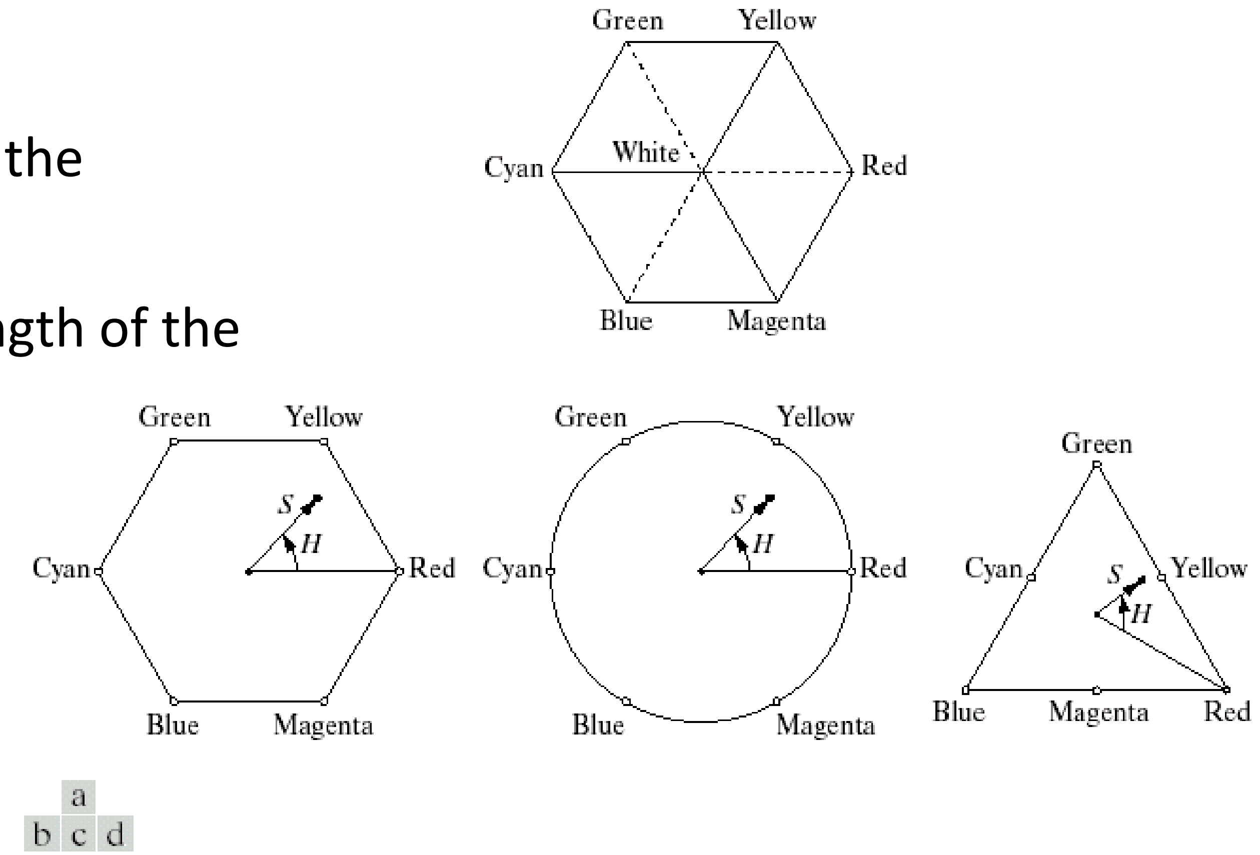


FIGURE 6.13 Hue and saturation in the HSI color model. The dot is an arbitrary color point. The angle from the red axis gives the hue, and the length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.

HSI Color Model

- Converting colors from RGB to HIS
  - Hue component

$$H = \begin{cases} \theta \text{ if } B \le G \\ 360 - \theta \ \text{ if } B > G \end{cases}$$

with

$$\theta = \cos^{-1}\left[\frac{\frac{1}{2}\{(R-G)+(R-B)\}}{\{(R-G)^2+(R-B)(G-B)\}^{1/2}} \right]$$

  - Saturation component

$$S = 1 - \frac{3}{(R+G+B)}[\min(R,G,B)]$$

  - Intensity component

$$I = \frac{1}{3}(R+G+B)$$

RGB values have been normalized to the range [0,1]

Angle θ is measured with respect to the red axis

Hue can be normalized to the range [0, 1] by dividing by 360°c

HSI Color Model

Converting colors from HSI to RGB

- Three sectors of interest, corresponding to the 120^0 intervals in the separation of primaries

- GB sector $(120^\circ \le H < 240^\circ)$

$$H = H - 120^o$$

$$R = I(1 - S)$$

$$G = I\left[1 + \frac{S\cos H}{\cos(60^o - H)}\right]$$

$$B = 3I - (R + G)$$

- BR sector $(240^\circ \le H < 360^\circ)$

$$H = H - 240^o$$

$$G = I(1 - S)$$

$$B = I\left[1 + \frac{S\cos H}{\cos(60^o - H)}\right]$$

$$R = 3I - (G + B)$$

Converting colors from HSI to RGB

- Example 6.2
  - The HSI values corresponding to the image of the RGB color cube

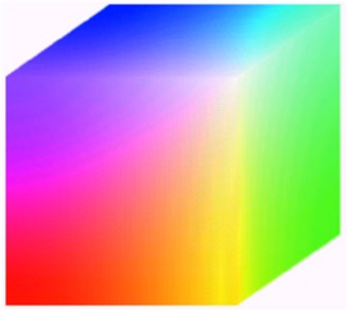
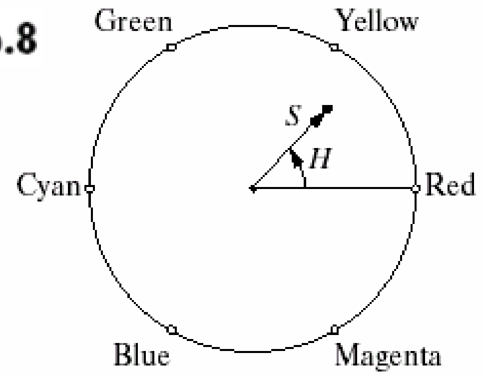
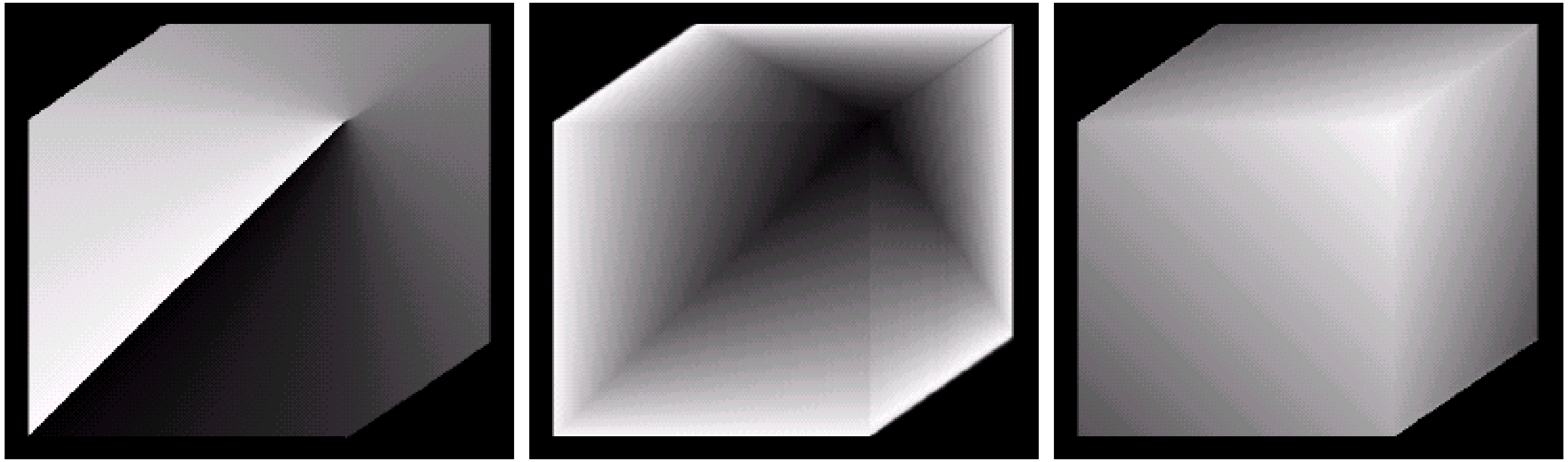


FIGURE 6.8



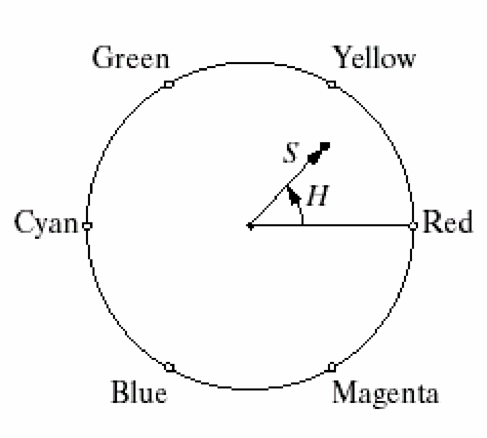


a b c

FIGURE 6.15 HSI components of the image in Fig. 6.8. (a) Hue, (b) saturation, and (c) intensity images.

Converting colors from HSI to RGB

❖ Manipulating HSI component images



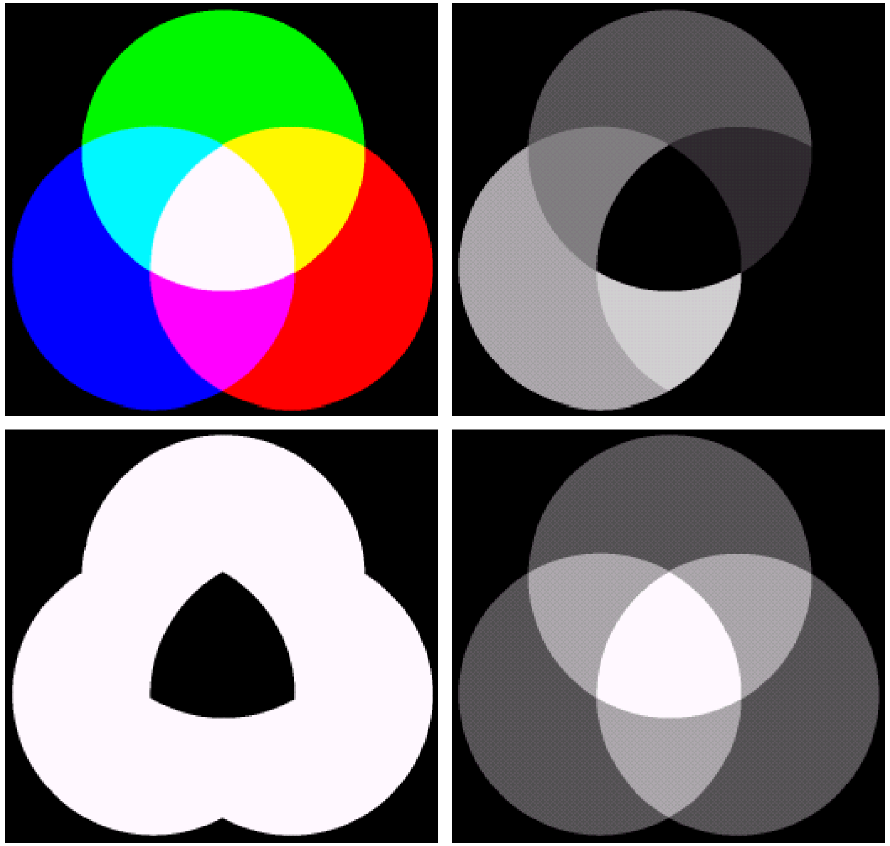


FIGURE 6.16 (a) RGB image and the components of its corresponding HSI image: (b) hue, (c) saturation, and (d) intensity.

Converting colors from HSI to RGB

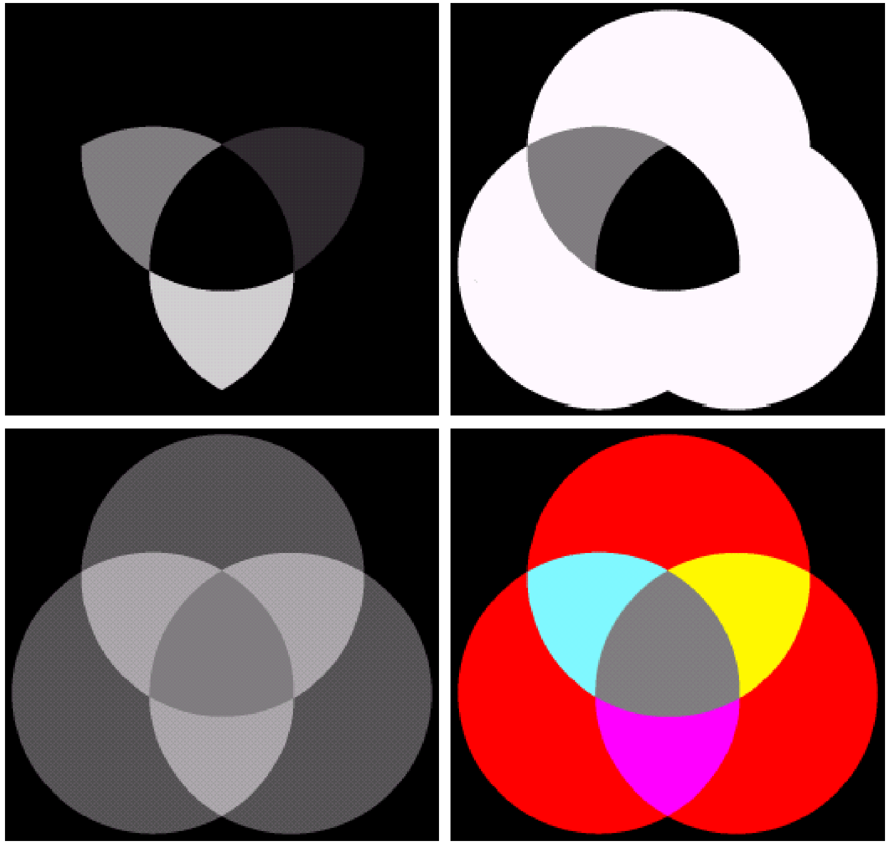


FIGURE 6.17 (a)–(c) Modified HSI component images. (d) Resulting RGB image. (See Fig. 6.16 for the original HSI images.)

Processing of color images

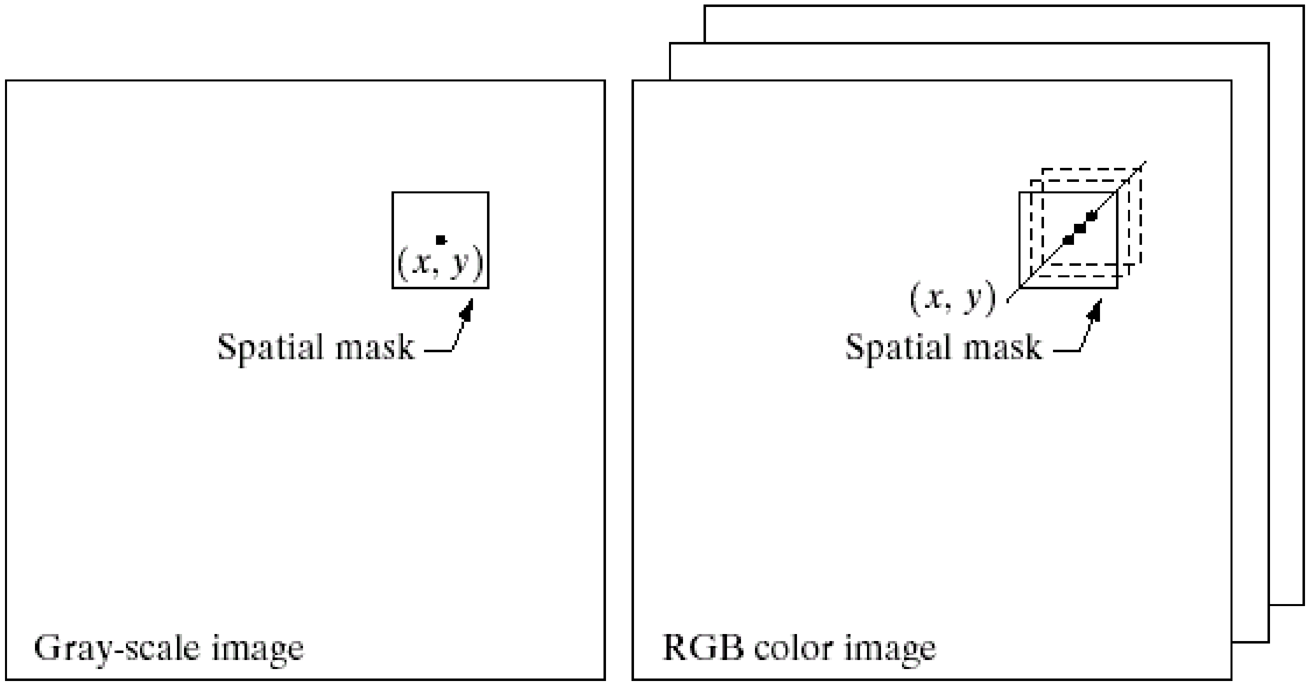
- Any kind of color image processing can be implemented in two alternative ways:
  - Each color channel should be processed separately, in general using even different filters with different parameters. Moreover, one or two color channels may remain unprocessed
  - A luminosity information can be extracted from an RGB image; then, after its processing, it can be inserted back into the image

Processing of color images

- A pixel at (x,y) is a vector in the color space
    - RGB color space

$$\mathbf{c}(x,y) = \begin{bmatrix} R(x,y) \\ G(x,y) \\ B(x,y) \end{bmatrix}$$

Processing of color images in spatial domain



a b

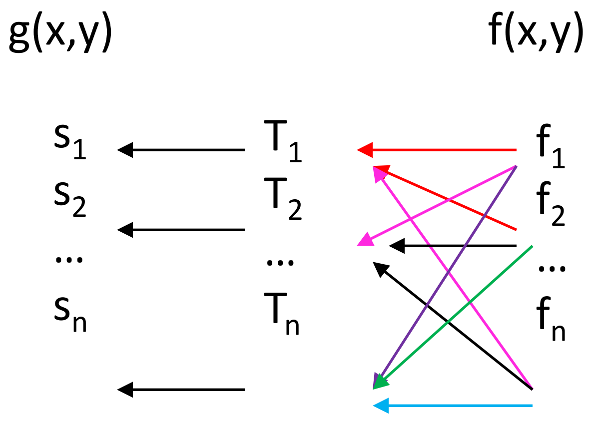
FIGURE 6.29 Spatial masks for gray-scale and RGB color images.

Color Transformations

- Similar to gray scale transformation
  - $g(x,y)=T[f(x,y)]$

- Color transformation

$$s_i = T_i(r_1, r_2, \ldots, r_n), \quad i = 1,2,\ldots,n$$



Color Transformations

- Formulation

$$g(x, y) = T[f(x, y)]$$

  - $f(x, y)$ is a color input image
  - $g(x, y)$ is the transformed or processed
  - T is an operator

– Transformation or color mapping functions

$$s_i = T_i(r_1, r_2, \ldots, r_n)$$

  - n is the number of color components
  - The color components of $f(x, y)$ and $g(x, y)$ at any point
  - $\{T_1, T_2, \ldots, T_n\}$ is a set of transformation

Color Transformations

- Some operations are better suited to specific models.

$$g(x, y) = kf(x, y)$$

- In the HIS color space, this can be done with the simple transformation

$$s_3 = kr_3, \quad where\ 0 < k < 1$$

- In the RGB color space, three components must be transformed:

$$s_i = kr_i \quad i = 1,2,3.$$

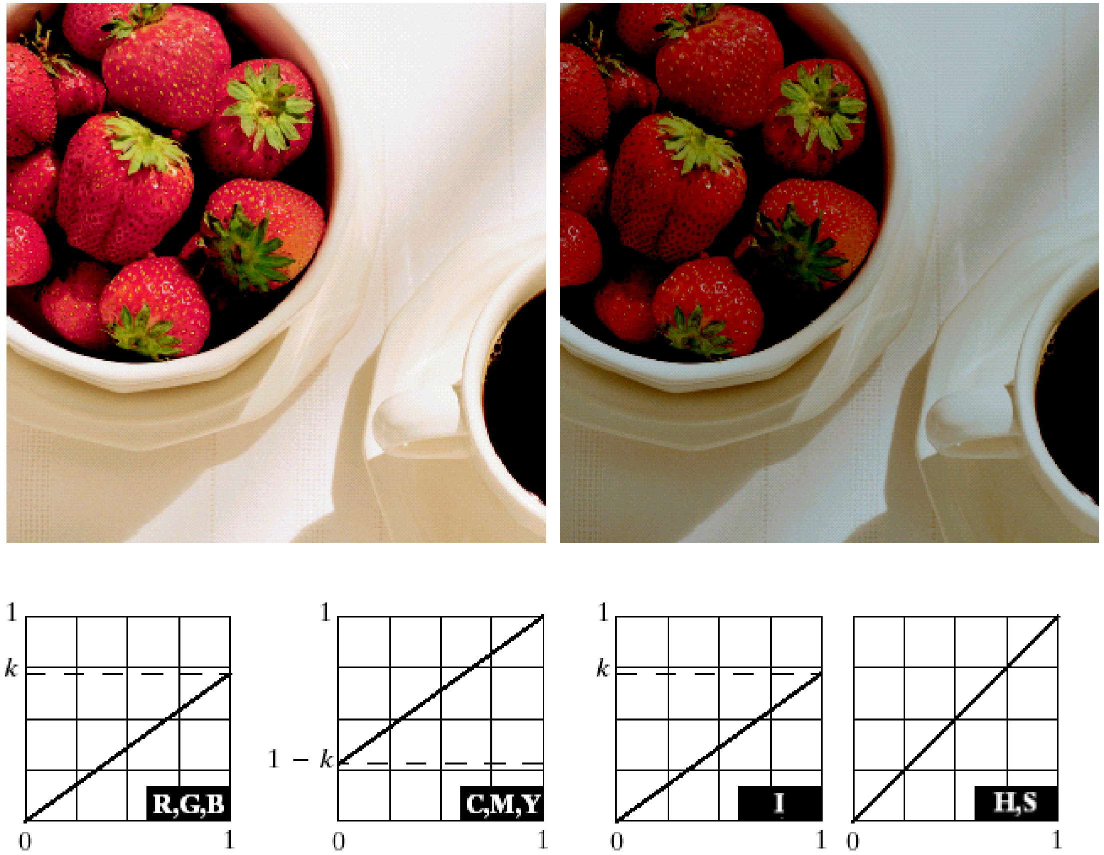
- The CMY space requires a similar set of tranfomations:

$$s_i = kr_i + (1 - k),\ i = 1,2,3.$$

Color Transformations

FIGURE 6.30 A full-color image and its various color-space components. (Original image courtesy of Med-Data Interactive.)

Color Transformations



a b
c d e

FIGURE 6.31 Adjusting the intensity of an image using color transformations. (a) Original image. (b) Result of decreasing its intensity by 30% (i.e., letting $k = 0.7$). (c)–(e) The required RGB, CMY, and HSI transformation functions. (Original image courtesy of MedData Interactive.)

- It is important that to note that each transformation defined in Eqs.(6.5-4) through (6.5-6) depends only on one component within its color space

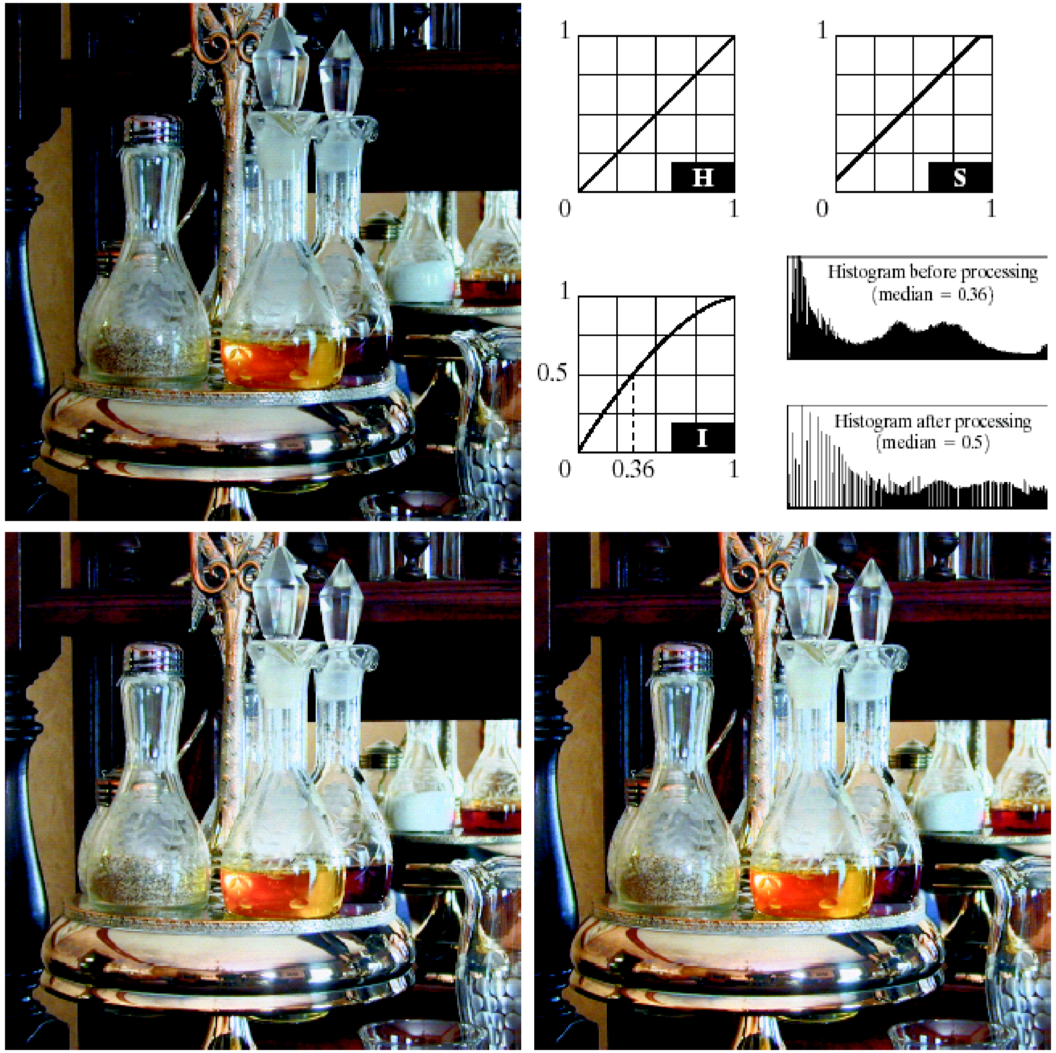
Histogram Processing

- Histogram equalization
  - A transformation that seeks to produce an image with a uniform histogram of intensity values
- Color images
  - Composed of multiple components
  - The gray-scale technique to more than one component and/or histogram
  - A more logical approach
    - To spread the color intensities uniformly, leaving the colors themselves(e.g., hues) unchanged.
    - HSI color space is ideally suited to this type approach.

Histogram Processing

a	b
c	d

FIGURE 6.37 Histogram equalization (followed by saturation adjustment) in the HSI color space.



Low-pass fileting (Smoothing) and Sharpening

- The next step beyond transforming each pixel of a color image without regard to its neighbors (as in the previous section) is to modify its value based on the characteristics of the surrounding pixels

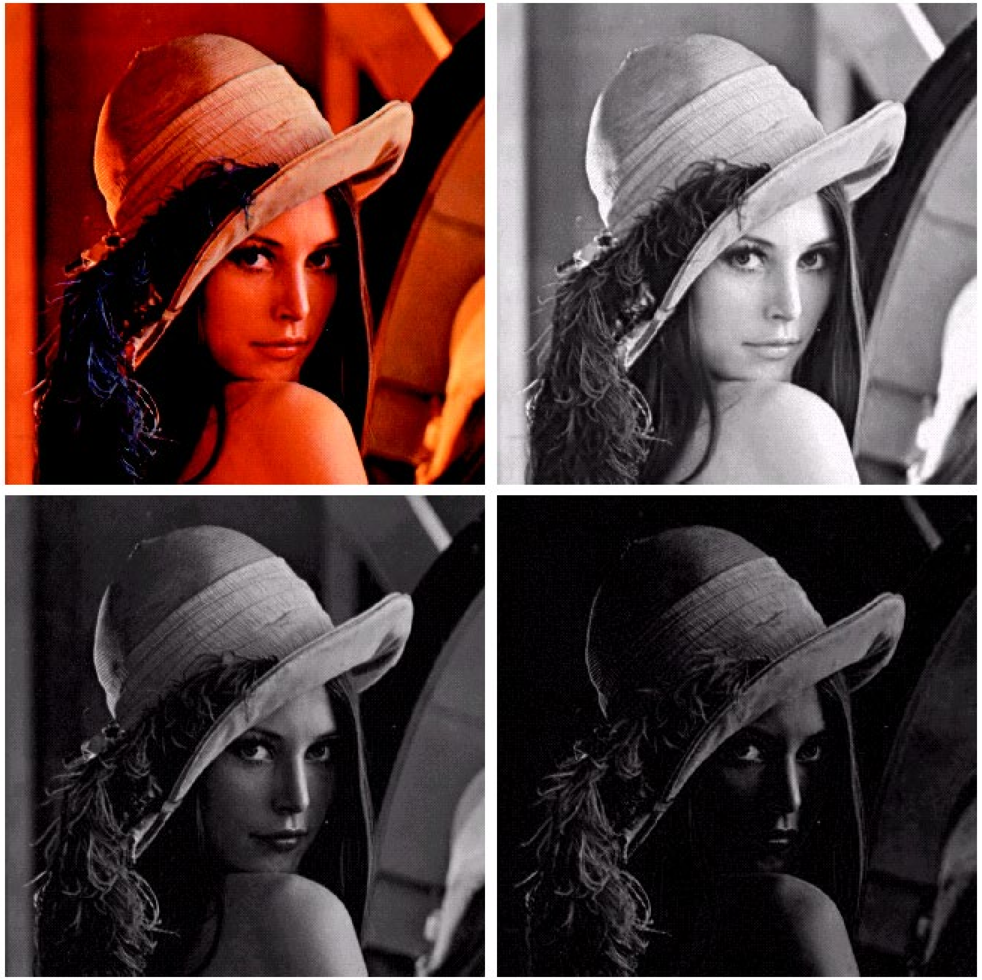
- The basics of neighborhood processing are illustrated within the context of color image smoothing and sharpening.

Color Image Smoothing

- The basics of neighborhood processing
  - As a spatial filtering operation in which the coefficients of the filtering mask are all 1's
  - The mask is slid across the image to be smoothed
  - Each pixel is replaced by the average of the pixels in the neighborhood defined by the mask

$$\bar{c}(x, y) = \begin{bmatrix} \dfrac{1}{K} \displaystyle\sum_{(x,y)\in S_{xy}} R(x, y) \\ \dfrac{1}{K} \displaystyle\sum_{(x,y)\in S_{xy}} G(x, y) \\ \dfrac{1}{K} \displaystyle\sum_{(x,y)\in S_{xy}} B(x, y) \end{bmatrix}$$

Color Image Smoothing



a b
c d

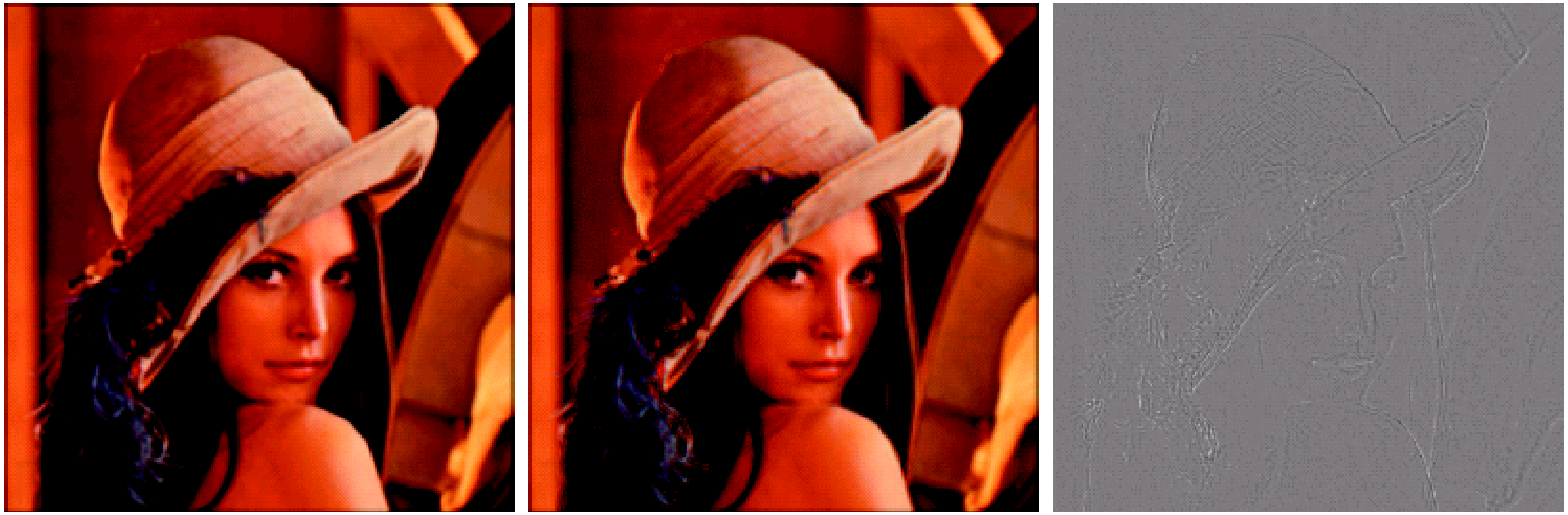
FIGURE 6.38
(a) RGB image.
(b) Red component image.
(c) Green component.
(d) Blue component.

Color Image Smoothing

a b c

FIGURE 6.39 HSI components of the RGB color image in Fig. 6.38(a). (a) Hue. (b) Saturation. (c) Intensity.

Color Image Smoothing



a b c

FIGURE 6.40 Image smoothing with a 5×5 averaging mask. (a) Result of processing each RGB component image. (b) Result of processing the intensity component of the HSI image and converting to RGB. (c) Difference between the two results.

Color Image Sharpening

- Use the Laplacian (same as smoothing)

FIGURE 6.41 Image sharpening with the Laplacian. (a) Result of processing each RGB channel. (b) Result of processing the intensity component and converting to RGB. (c) Difference between the two results.

Processing of color images

- Separate processing of color channels is reasonable if, for example these channels are corrupted by different noises or if it is necessary to correct or enhance colors

- An intensity channel in the HIS space or luminosity channel in YUV space can be processed if only the luminosity information is corrupted

Color Edge Detection

- By gradient operators
- The gradient discussed in section 3.7.3 is not defined for vector for quantities

$$\nabla f = mag(\nabla \mathbf{f}) = [G^2{}_x + G^2{}_y]^{1/2} = [(\frac{\partial f}{\partial x})^2 + (\frac{\partial f}{\partial y})^2]^{1/2}$$

- Computing the gradient on individual images and then using the results to form a color image will lead to erroneous results

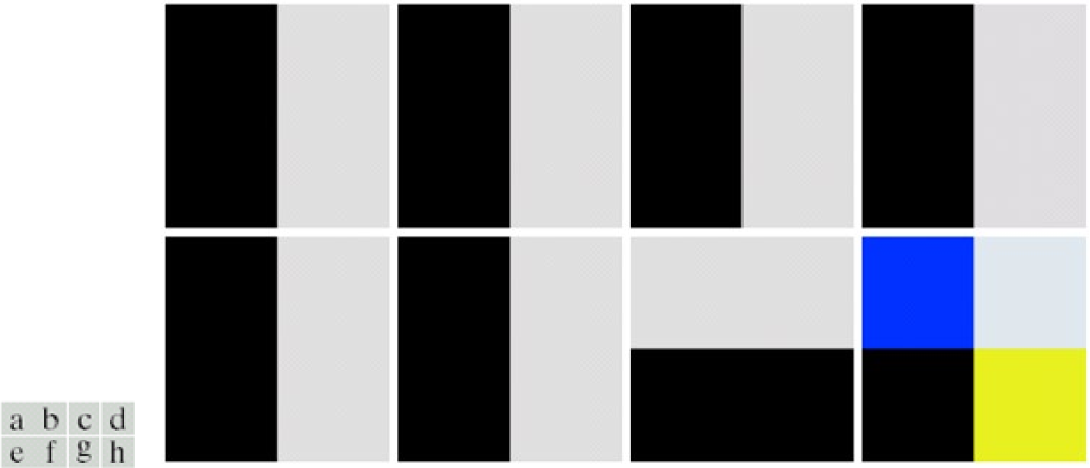


FIGURE 6.45 (a)–(c) R, G, and B component images and (d) resulting RGB color image. (f)–(g) R, G, and B component images and (h) resulting RGB color image.

Color Edge Detection

- Definition of the gradient applicable to vector quantities : method by Di Zenzo
  - The gradient(magnitude and direction)of the vector c

$$\mathrm{u} = \frac{\partial R}{\partial x}\mathrm{r} + \frac{\partial G}{\partial x}\mathrm{g} + \frac{\partial B}{\partial x}\mathrm{b}$$

$$\mathrm{v} = \frac{\partial R}{\partial y}\mathrm{r} + \frac{\partial G}{\partial y}\mathrm{g} + \frac{\partial B}{\partial y}\mathrm{b}$$

$$g_{xx} = \mathrm{u}\cdot\mathrm{u} = \mathrm{u}^T\mathrm{u} = \left|\frac{\partial R}{\partial x}\right|^2 + \left|\frac{\partial G}{\partial x}\right|^2 + \left|\frac{\partial B}{\partial x}\right|^2$$

$$g_{yy} = \mathrm{v}\cdot\mathrm{v} = \mathrm{v}^T\mathrm{v} = \left|\frac{\partial R}{\partial y}\right|^2 + \left|\frac{\partial G}{\partial y}\right|^2 + \left|\frac{\partial B}{\partial y}\right|^2$$

$$g_{xy} = \mathrm{u}\cdot\mathrm{v} = \mathrm{u}^T\mathrm{v} = \frac{\partial R}{\partial x}\frac{\partial R}{\partial y} + \frac{\partial G}{\partial x}\frac{\partial G}{\partial y} + \frac{\partial B}{\partial x}\frac{\partial B}{\partial y}$$

Color Edge Detection

- The direction of maximum rate of change of

$$\theta = \frac{1}{2}\tan^{-1}\left[\frac{2g_{xy}}{(g_{xx} - g_{yy})}\right]$$

- The value of the rate of change at (x, y)

$$F(\theta) = \left\{\frac{1}{2}[(g_{xx} + g_{yy}) + (g_{xx} - g_{yy})\cos 2\theta + 2g_{xy}\sin 2\theta]\right\}^{\frac{1}{2}}$$

Color Edge Detection

a b
c d

FIGURE 6.46 (a) RGB image. (b) Gradient computed in RGB color vector space. (c) Gradients computed on a per-image basis and then added. (d) Difference between (b) and (c).

Color Edge Detection

a b c

FIGURE 6.47 Component gradient images of the color image in Fig. 6.46. (a) Red component, (b) green component, and (c) blue component. These three images were added and scaled to produce the image in Fig. 6.46(c).

Noise in Color Image

- The noise content of a color image
  - The same characteristics in each color channel
  - Possible for color channels to be affected differently by noise

- Different noise level
  - Caused by differences in the relative strength of illumination available to each of the color channels
  - For example(use of a red filter : CCD camera)
    - **CCD sensors are noisier at lower levels of illumination**

Noise in Color Image

a b
c d

FIGURE 6.48 (a)–(c) Red, green, and blue component images corrupted by additive Gaussian noise of mean 0 and variance 800. (d) Resulting RGB image. [Compare (d) with Fig. 6.46(a).]

Noise in Color Image

- The hue and saturation components are degraded due to the nonlinearity of the cos and min operation.
- The intensity image is the average of the RGB images.

a b c

FIGURE 6.49 HSI components of the noisy color image in Fig. 6.48(d). (a) Hue. (b) Saturation. (c) Intensity.